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TEXT ACCOMPANYING GMS-46

Geology of the Breitenbush River Area, Linn and Marion Counties, Oregon

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Structural Geology

The area is cut by a major N. 22° E.-trending fault that is here referred to as the "Hoover fault" for its exposure on the east end of Hoover Ridge. The Hoover fault separates northwest-tilted rocks of unit **Tbl** on Hoover Ridge from younger rocks east of the fault. The youngest rock cut by the fault is unit **Tbu**, where it is interbedded with unit **Ts**. No ages are available for the lower part of unit **Tbu**. Interbedded lavas of unit **Ts** have a minimum age of 19.4 million years (Ma) (White, 1980a,b; Fiebelkorn and others, 1982). The total down-to-the-southeast offset across the Hoover fault is unknown, but unit **Tbq** is about 300 m higher in elevation on the northwest side of the fault than on the southeast side between Beard Saddle (outside of the map boundary) and Tom Creek. Unit **Tbq** apparently dips toward the southeast at Tom Creek, so the net slip is probably smaller than the difference in elevation. The Tom Creek area is the only place where the same unit has been found on both sides of the Hoover fault. The fault mapped at Tom Creek is very close to the edge of the map, so more faulting could be present west of the map boundary. It may be that the fault has lesser net slip in the Tom Creek area than in areas to the north. It is also possible that there is an angular unconformity between units **Tbq** and **Tbl**. Dips in unit **Tbl** near Stahlman Point (west of the map boundary near Beard Saddle) are toward the northwest, whereas overlying rocks of units **Ts** and **Tbq** appear to have subhorizontal dips. This discordance in dips suggests that a period of deformation and erosion preceded unit **Tbq**. Therefore, some deformation could have occurred on the Hoover fault prior to unit **Tbq** time that would not be detectable as offsets of unit **Tbq**. Additional mapping in the Stahlman Point-Beard Saddle area is critical to resolution of this problem.

Rocks on the east block of the Hoover fault have mostly subhorizontal or gentle southeasterly to southwesterly dips, unless they have been deformed adjacent to the Hoover fault. Numerous small faults tilt the east-block rocks on the western margin of Boulder Ridge. The largest block is tilted toward the northwest in the Cliffs Creek area. This local fault block is separated on its southeast side from the rest of the east-block rocks by a northeast-trending subsidiary fault that is exposed on the ridge separating Cliffs and Cultus Creeks. The exposed fault plane strikes N. 35° E., dips 63° to the southeast, and has slickensides raking 23° to the southwest. Unit **Tbq** is locally offset a maximum of about 240 m down toward the northwest across the fault. If the exposed slickensides and dip are representative of the direction of net slip and the attitude on the entire fault zone, then the fault is a high-angle reverse fault with left-lateral oblique slip. However, the irregular trace of the fault across the topography offers no support for the easterly dip or for a large component of strike-slip movement. If the irregular trace of the fault reflects a local irregularity in the fault plane, then this may not be relevant to the fault as a whole. The northwest-tilted sequence is separated from gently dipping east-block rocks to the northwest by an inferred fault that roughly follows the Breitenbush River. Stratigraphic offset across this inferred fault is difficult to estimate but is probably small, with the northwest side down. The northwest-tilted block thus appears to be a northeast-trending monoclinal flexure that has been broken at the flexure points. The net result is that the rocks northwest of the flexure are displaced downward relative to rocks southeast of the flexure. The flexure could be the result of secondary folding caused by a small component of left-lateral shear on the Hoover fault.

Although there is no evidence of large-scale compressional folding, the northwesterly dip of the rocks on the northwest side of the Hoover fault at Hoover Ridge and the southwest to southeast dip of rocks on the southeast side of the fault on Boulder Ridge can be interpreted to form a faulted anticlinal structure (see descriptions of the Breitenbush anticline by Thayer, 1939). The fact that the fold axis is coincident with faults introduces other possible interpretations. The southwestward dip of unit **Tbq** along Boulder Creek could be the southwestward-plunging nose of this anticline. However, if, as suggested above, units **Tbq** and **Tbl** are separated by an angular unconformity, then dips on the east block measured in unit **Tbq** and younger units may have little or no relationship to dips of unit **Tbl** on the west block of the Hoover fault. Even dips measured in rocks mapped as unit **Tbl** on the southeast block are not necessarily helpful, because it is not known with certainty whether unit **Tbl** on the southeast block is correlative to or even approximately contemporaneous with unit **Tbl** on the northwest block of the Hoover fault. It is possible that some northwestward-dipping rocks of unit **Tbl** lie beneath the southeast-block rocks mapped as unit **Tbl** and are separated from them by an angular unconformity. The "anticline" would, in that case, be an artifact of the faulting. The relatively high dip of the older rocks on the northwest block relative to the younger rocks of the east block and the abrupt change of dip across the Hoover fault support this interpretation.

If a marker unit contemporaneous with unit **Tbl** could be correlated across the Hoover fault, this would lend credence to the concept of an anticline. It would also help to establish the amount of offset that may have occurred before deposition of unit **Tbq**. For example, if unit **Tls**, which is conformable on top of northwesterly dipping rocks of unit **Tbl** at the mouth of the Breitenbush River (west of the map boundary), could be located on the southeast block, this would suggest that the sequence was folded. Drilling to 2.5 km on the southeast block (Sunedco Well No. 58-28) has failed to intercept either the unit **Tls** sequence or any other pre-**Tbq** unit that can be correlated across the Hoover fault. The unit **Tbl** sequence intercepted in Sunedco Well No. 58-28 appears to have a greater quantity of ash-flow tuff than is typical of unit **Tbl** cropping out on the northwest block. A highly altered, quartz-rich tuff intercepted in the lower part of the well is also not known to crop out anywhere on the northwest block. It is possible either that, owing to accidents of original rock distribution, no distinctive units correlate across the fault, or that dip-slip offset on the Hoover fault prior to the deposition of unit **Tbq** could be so large that the bottom of the 2.5-km-deep well is in units younger than any **Tbl** or **Tls** units that crop out on the northwest block of the fault. This amount of dip-slip would require an offset in excess of 4 km. This latter possibility could be tested either by deepening Sunedco Well No. 58-28 to see if unit **Tls** can be intercepted or by attempting to correlate the distinctive quartz-rich tuff from the lower part of the well to outcrops outside of the map area on the northwest block of the Hoover fault. If this extreme dip-slip offset is present, then the quartz-rich tuff should crop out somewhere above the unit **Tls** sequence on the northwest block.

Aside from some small-displacement, northwest-trending normal faults in the Outerson Mountain area (Clayton, 1976; Rollins, 1976); the only other major deformation in the map area is a northeast-trending fault, named the "Bruno fault," which crops out in a roadcut on the northeast flank of Mount Bruno. The Bruno fault strikes N. 30° E. and dips 80° to the southeast. The

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fault at the outcrop juxtaposes units **Tmd** and **Tmb** and is therefore younger than about 10 Ma. A flow of unit **Tp** dated at 6.1 Ma occurs on the southeast side of the Bruno fault on the southeast flank of Mount Bruno, but owing to the local lithologic similarity of units **Tmb** and **Tp**, it is not known for certain if the fault cuts unit **Tp** there. Unit **Tp** is apparently offset down to the east across the fault near Bruno Creek, although the palagonite-rich character of unit **Tp** on the east side of the fault versus the paucity of palagonite tuff in unit **Tp** west of the fault casts some doubt on the correlation. Down-to-the-east offset is also suggested by the increasing southeasterly dip of volcaniclastic interbeds in unit **Tp** as the postulated extension of the fault is approached from the east. These southeasterly dips could be caused by drag. If the palagonite-rich rocks on the east side of the projected fault are unit **Tp**, then there is dip-slip offset of about 370 m across the fault. The unit **Tp** sequence adjacent to the fault at Bruno Creek crops out at Bachelor Mountain, where the uppermost flow has a K-Ar age of 6.35 Ma. Unit **Tub** appears to thicken abruptly across the southwestward extension of the fault, suggesting that unit **Tub** is lapping onto an east-facing fault-line scarp. The base of unit **Tub** has K-Ar ages of 2.7 to 3.1 Ma, so the fault was active prior to about 3.1 Ma. The fault was therefore probably active sometime between 3.1 and 6.35 Ma.

The down-to-the-east offset and age of the Bruno fault are similar to ages and offsets inferred for faults bounding the west side of a regional graben in the High Cascades of central Oregon (Allen, 1966; Taylor, 1980). However, the N. 30° E. strike of the fault where it crops out does not match the nearly north-south trend of the postulated graben faulting. The fault is also west of the North Santiam River, not at the river, as inferred by Allen (1966). It is possible that the fault extends to the northeast through Woodpecker Ridge and the Sentinel Hills, where it is obscured by younger lavas. This extension cannot be proved with available stratigraphic information. The fault also apparently extends southward where it merges with a zone of down-to-the-east faulting with a more northerly trend (Black and others, 1987).

Mineralization

Samples from most of the intense alteration zones were analyzed for a broad spectrum of ore metals. Only one sample had a metal content above background levels. The sample came from a quartz-veined shear zone in a tuffaceous debris flow of unit **Tbl** at Hoover Ridge. The shear zone trends N. 55° W. and dips 82° to the northeast with horizontal slickensides. Drusy quartz with open boxworks containing abundant iron oxide was sampled. Two batches of quartz fragments were analyzed, both labeled NS-473. One sample has 57 parts per million (ppm) Cu, 1,394 ppm Pb, 10 ppm Zn, 1 ppm Mo, 3.6 ppm Ag, and <5 parts per billion (ppb) Au. The other sample has 175 ppm Cu, 2,722 ppm Pb, 40 ppm Zn, <1 ppm Mo, 8.6 ppm Ag, and 35 ppb Au. The analyses were performed by Chemex Labs Ltd., North Vancouver, B.C., utilizing quantitative and semiquantitative multielement induction coupled plasma (ICP) analysis, except for Au, which was determined by fire assay/atomic absorption (AA). The sample location is in a roadcut at sec. 29 Dbacc, T. 9 S., R. 6. E., long 122°5'53" W., lat 44°45'44" N.

Walker and others (1985) found anomalous contents of metallic elements in rocks and stream sediments from the Battle Creek area and in rocks from the ridge immediately east of Dunlap Lake. The former area had rock samples with maximum values of >20,000 ppm Cu, 150 ppm Pb, 500 ppm Zn, 7 ppm Mo, 200 ppm Ag, and 350 ppb Au. The latter area had rock samples with maximum values of 20 ppm Cu, 20 ppm Pb, <200 ppm Zn, 20 ppm Mo, 15 ppm Ag, and 150 ppb Au. The analyses were obtained by semiquantitative spectrographic analysis. Walker and others (1985) concluded that these areas have moderate mineral potential.

Geothermal Resources

Thermal fluid has been encountered at two localities in the map area. Thermal fluid reaches the surface at Breitenbush Hot Springs, and a thermal aquifer was encountered in Sunedco Well No. 58-28 at a depth of 752 to 782 m. The hot springs have a temperature of about 86 °C (Mariner, 1985), with temperatures in adjacent shallow wells as high as 110 °C at 100 m (Blackwell and others, 1981). The thermal aquifer in Sunedco Well No. 58-28 had a temperature of 136 °C, when measured by a maximum-reading thermometer during drilling (A. Waibel, unpublished data, 1982). A thermistor log run about six months after drilling measured a maximum temperature of about 115 °C in the same part of the well (Blackwell and others, 1986). The second temperature reading was taken after the aquifer had been cemented off and cased. It is possible that injected cement and drilling fluid may have disturbed the natural flow of water in the aquifer enough to account for the discrepancy between the two temperature readings. The complete temperature-depth profile of Sunedco Well No. 58-28 is not available, but, from data in hand (A. Waibel, unpublished data, 1982; Blackwell and others, 1986), it is apparent that the thermal aquifer has raised the temperature gradient above regional background values (Priest, 1985). No stable temperature readings are available for the lower part of Sunedco Well No. 58-28, but the maximum recorded bottom-hole temperature of 141 °C (A. Waibel, unpublished data, 1982) is consistent with a minimum background gradient of about 56 °C/km (Priest, 1985). This gradient is consistent with gradients expected for sites in the Cascade heat-flow anomaly of Blackwell and others (1978, 1982) (Priest, 1985).

Thermal fluids in the area occur in unit **Ts** near its lower contact with unit **Tbq** or in unit **Tbq**. The hot springs emerge from fractures in unit **Ts** near the contact with underlying unit **Tbq**. The thermal aquifer in Sunedco Well No. 58-28 is located in fractured and sheared tuff of unit **Tbq** near the contact with overlying unit **Ts** (see cross section). Anomalously high temperature gradients occur near the hot springs and near Sunedco Well No. 58-28. The gradients decrease gradually toward the east and fall off abruptly to background values a short distance to the west of the well (Blackwell and others, 1986). This is consistent with an easterly dipping heat source, probably the aquifer intercepted in the well (A. Waibel, personal communication, 1985). The dip of the Breitenbush Tuff in the area adjacent to the well is approximately 10° to the east-southeast. The thermal fluid may thus be flowing upward along permeable zones in the tuff from sources under the High Cascades to the east. If the fluid cools by conduction and mixing with cooler fluids as it flows, then it may be significantly hotter to the east. Estimated reservoir temperatures for Breitenbush Hot Springs are 176 °C (sulfate-water method), 174 °C (anhydrite method), 166 °C (quartz method), and 148 °C (Na-K-Ca method) (Mariner, 1985). The higher estimated temperatures are probably most representative of the actual reservoir temperature (Mariner, 1985). The proposed geothermal model could be tested by drilling and sampling a 2-km hole at sec. 36 Ddd, T. 9 S., R. 7. E.

Analytical Procedures

Approximately 165 whole-rock chemical analyses were utilized in the study to help define and characterize stratigraphic units and to search for economic minerals. These data will be presented in an open-file report to be published by the Oregon Department of Geology and Mineral Industries. The data were generated by atomic absorption spectrophotometry, Christine McBirney, analyst, University of Oregon, and by quantitative and semiquantitative multielement ICP analysis at Chemex Labs, Ltd. Multiple splits of samples and previously analyzed samples were submitted to aid in quality control.

K-Ar data were generated by Robert Duncan, Oregon State University, Corvallis, Oregon, and Paul Damon, University of Arizona, Tucson, Arizona, utilizing standard methods. $^{40}Ar/^{39}Ar$ data were generated by Daniel Lux, University of Maine, Orono, Maine, utilizing standard methods. In some cases, where the radiometric dates were obviously in error (e.g., an older date stratigraphically above a younger date), the samples were rerun. In most cases, the dates were exactly the same in the second run, suggesting that the errors were not in the analysis but were in the assumption that the isotopic systems had been closed to K and/or Ar exchange.

Acknowledgments

The map was reviewed by Richard M. Conrey, Washington State University; Paul E. Hammond, Portland State University; David R. Sherrod, *U.S. Geological Survey (USGS)*; and Norman S. MacLeod, Thomas P. Thayer, and George W. Walker, USGS, retired. Their comments and suggestions added greatly to the quality of the map. Britt Von Thaden, Rebecca A. Heisler, John Doerr, and Eileen L. Webb assisted in compilation and collection of the field and laboratory data. Gary Baxter supervised quality control on chemical data. Albert Waibel, Columbia Geoscience, provided interpretations and unpublished logs of the geothermal well data released by Sunedco Energy and Development Company. Sunedco is to be congratulated for its efforts to help geothermal and geologic research in the area by releasing its data to the public. The United States Department of Energy provided partial support for the analytical work and field work.

Table 1. (See accompanying map.)

Table 2. $^{40}Ar/^{39}Ar$ data for samples from units Tp and Tmb in map area and from unit Tls in Hall Ridge area west of map area

Sample no.	Geologic unit	J	Plateau age (Ma ± 1σ)	Total fusion age (Ma)	Temp. (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	Moles ^{39}Ar	^{39}Ar (%)	$^{40}Ar_{rad}$ (%)	K/Ca	Apparent age (Ma)	Location T.(S.)/R.(E.)/sec.	Latitude (N.)	Longitude (W.)
NS-462-W	Tp	0.006097	6.10 ± 0.91	5.98	865	3.32	2.4084	0.0099	505.3	43.2	17.0	0.2031	6.21 ± 0.16	11/7/4 Bdbd	44°39′00″	121°57′23″
					985	2.86	7.9830	0.0100	353.3	30.2	17.6	0.0610	5.58 ± 0.26			
					1065	3.23	10.7515	0.0119	173.1	14.8	16.7	0.0452	5.96 ± 0.66			
					1155	4.65	18.9252	0.0190	93.1	8.0	11.5	0.0255	5.97 ± 1.80			
					FUSE	11.84	34.1494	0.0473	44.6	3.8	5.1	0.0140	6.77 ± 2.67			
					Total				1169.4	100.0						
NS-328-W	Tmb	0.006077	6.45 ± 0.46	8.56	825	2.62	8.3288	0.0091	238.9	46.6	21.8	0.0585	6.30 ± 0.65	10/7/35 Ddbd	44°39′23″	121°56′56″
					925	2.45	9.0770	0.0086	133.4	26.0	24.4	0.0536	6.60 ± 0.70			
					1000	3.41	14.9949	0.0124	26.4	5.2	27.1	0.0323	10.23 ± 3.40			
					1075	5.28	22.9189	0.0210	32.8	6.4	17.2	0.0210	10.07 ± 3.77			
					1145	9.57	28.8951	0.0376	38.4	7.5	8.1	0.0166	8.69 ± 5.20			
					FUSE	18.66	29.7659	0.0636	42.7	8.3	12.0	0.0161	24.97 ± 1.78			
					Total				512.6	100.0						
NP-826-P	Tls	0.005564	—	26.46	825	5.85	6.7180	0.0106	179.7	17.7	55.2	0.0726	32.28 ± 0.41	9/5/35 Cdac	44°44′34″	122°09′40″
					900	3.42	5.6900	0.0044	304.2	30.0	74.7	0.0857	25.57 ± 0.31			
					940	3.19	5.1220	0.0036	203.7	20.1	78.3	0.0953	25.01 ± 0.42			
					1000	3.17	4.9430	0.0040	120.0	11.8	74.5	0.0988	23.68 ± 0.40			
					1025	3.83	5.3640	0.0058	59.7	5.9	65.8	0.0910	25.23 ± 1.37			
					1050	5.14	4.2900	0.0100	83.4	8.2	48.7	0.1139	25.03 ± 0.99			
					FUSE	4.70	12.8200	0.0101	63.0	6.2	57.6	0.0379	27.25 ± 0.99			
					Total				1013.7	100.0						

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STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

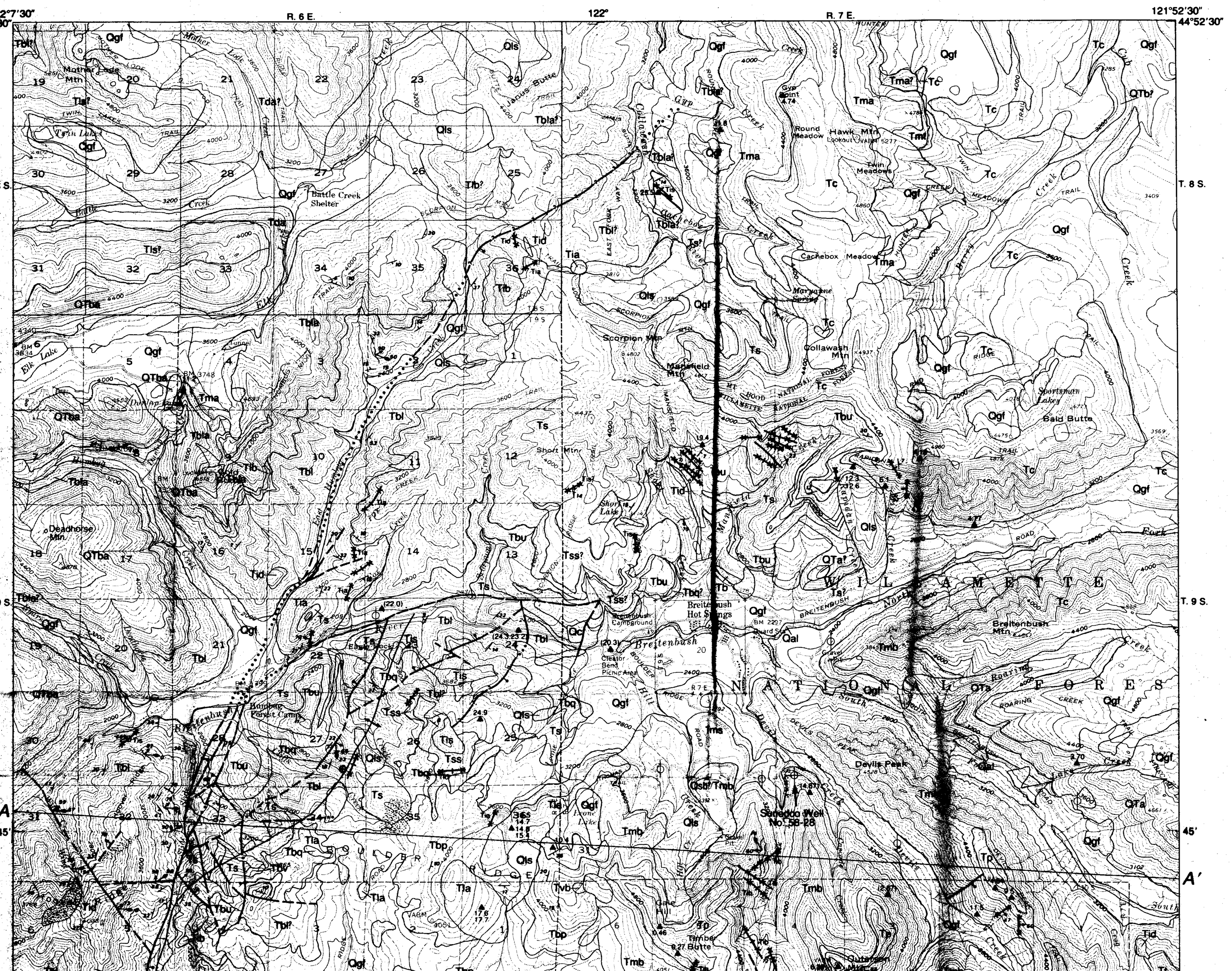
GEOLOGIC MAP OF THE BREITENBUSH RIVER AREA, LINN AND MARION COUNTIES, OREGON

1987

GMS-46

Geologic Map of the Breitenbush River Area, Linn and Marion Counties, Oregon

By G.R. Priest and others

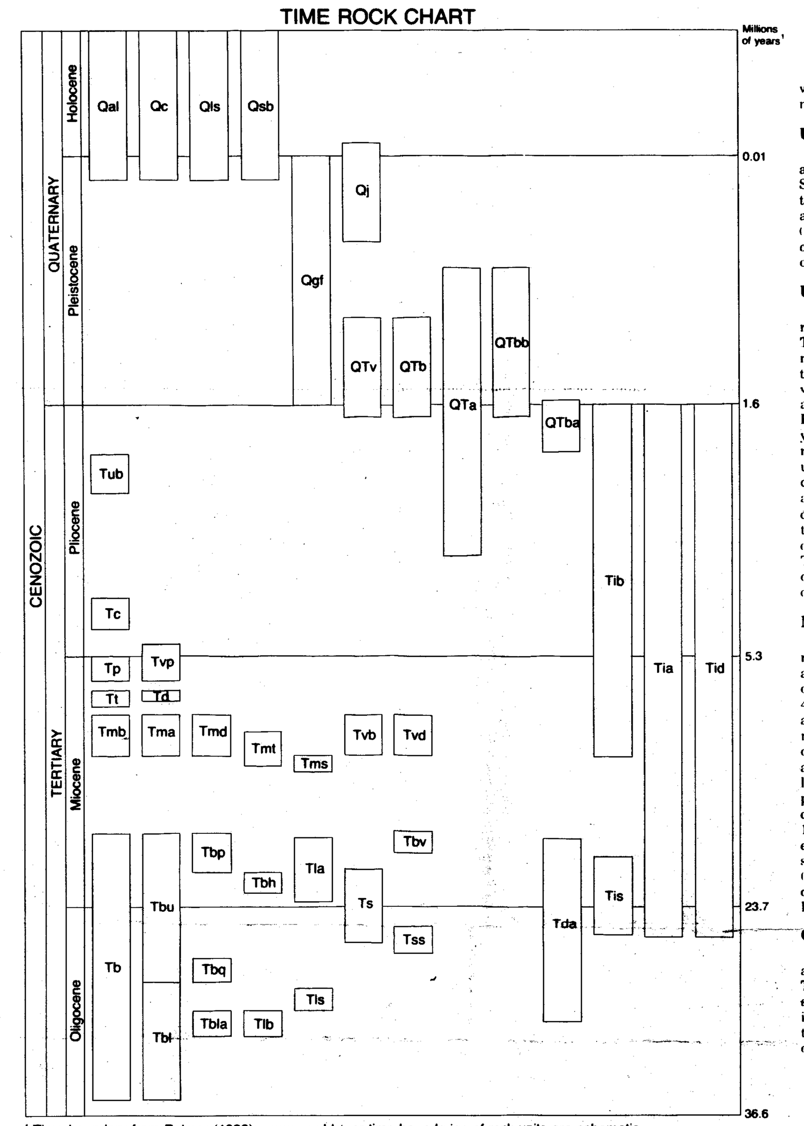


Geology by George R. Priest, Neil M. Woller, and Mark L. Ferns, Oregon Department of Geology and Mineral Industries.

CONTOUR INTERVAL 80 FEET

Scale 1:62,500

TIME ROCK CHART



DESCRIPTION OF REGIONAL TIME-ROCK UNITS

Introduction

The volcanic rocks in the area have been informally subdivided into four regional time-rock units. This was done in order to allow the units to be conveniently correlated to regional units utilized on other geologic maps of the Cascade Range.

Upper Pliocene and Quaternary volcanic and volcaniclastic rocks

This time-rock unit consists of rocks of various compositions that crop out in benches or plateaus that are intracanyon fillings in present stream valleys or in stream valleys that closely parallel present valleys. Subophitic to ophitic textures are common in basalts of the sequence; some are diktytaxitic. The base of the sequence is not dated but is estimated to be between about 3.7 and 4.2 Ma (see discussions of units **QTa** and **Tc**, respectively). The top of the sequence includes the post-glacial block-and-ash flow of Mount Jefferson (unit **Qj**). The rocks are equivalent to the volcanic rocks of the late High Cascades episode of Priest and others (1982, 1983) and to the upper part of the volcanic rocks of the High Cascade Range and Boring Lava of Peck and others (1964).

Upper Miocene and lower Pliocene volcanic and volcaniclastic rocks

This time-rock unit consists of basaltic lavas (units **Tp** and **Tc**) with minor amounts of tuff (unit **Tt**) and rhyodacite (unit **Td**), which unconformably overlie the middle and upper Miocene rocks (units **Tmb**, **Tma**, **Tmd**, **Tmt**, and **Tms**). The relief on the erosional surface of unconformity increases from about 150 m to more than 370 m from the oldest (units **Tp**, **Tt**, and **Td**) to the youngest (unit **Tc**) part of the section. Unlike the upper Pliocene and Quaternary volcanic rocks, which form obvious flat-topped benches in present stream valleys, these lavas crop out on the highest peaks of the Western Cascades. This geomorphic characteristic and the isotopic ages of these volcanic and volcaniclastic rocks were used to separate them from the upper Pliocene to Quaternary section. Compositionally, the rocks of this sequence are identical to many of the younger and older volcanic rocks. The most mafic lavas of the sequence are less silicic than the most mafic rocks in underlying sequences, but the bulk of the sequence is identical in composition to the middle and upper Miocene sequence. The middle and upper Miocene rocks are, however, slightly more altered, with common alteration of olivine and, less commonly, orthopyroxene to green phyllosilicates. The upper Miocene and lower Pliocene lavas generally have a fresher, lighter color than the older lavas, weather to a light-tan color, and have more basalt with medium-grained ophitic and subophitic texture. The age of the base of the sequence is unknown but is older than about 6.35 Ma and younger than about 10 Ma (see discussion of unit **Tp** and **Tmb**, respectively). The top of the sequence is about 4.2 Ma (see description of unit **Tc**). This time-rock unit is equivalent to the volcanic rocks of the early High Cascade episode of Priest and others (1982, 1983) and the lower part of the volcanic rocks of the High Cascade Range and Boring Lava of Peck and others (1964).

Middle and upper Miocene volcanic and volcaniclastic rocks

This time-rock unit consists of basalt and basaltic andesite (unit **Tmb**), andesite (unit **Tma**), dacite and rhyodacite (unit **Tmd**), with interbedded volcaniclastic sediments (unit **Tms**) and ash-flow tuff (unit **Tmt**), all of which unconformably overlie the Breitenbush Tuff and associated lavas and are unconformably overlain by unit **Tp** and younger rocks. This sequence fills a paleotopographic surface with about 200 to 400 m of relief. The rocks generally show some alteration of glass and mafic silicates, especially olivine and rarely orthopyroxene, to green or yellow-green phyllosilicates. The lavas are compact to vesicular but [illegible]

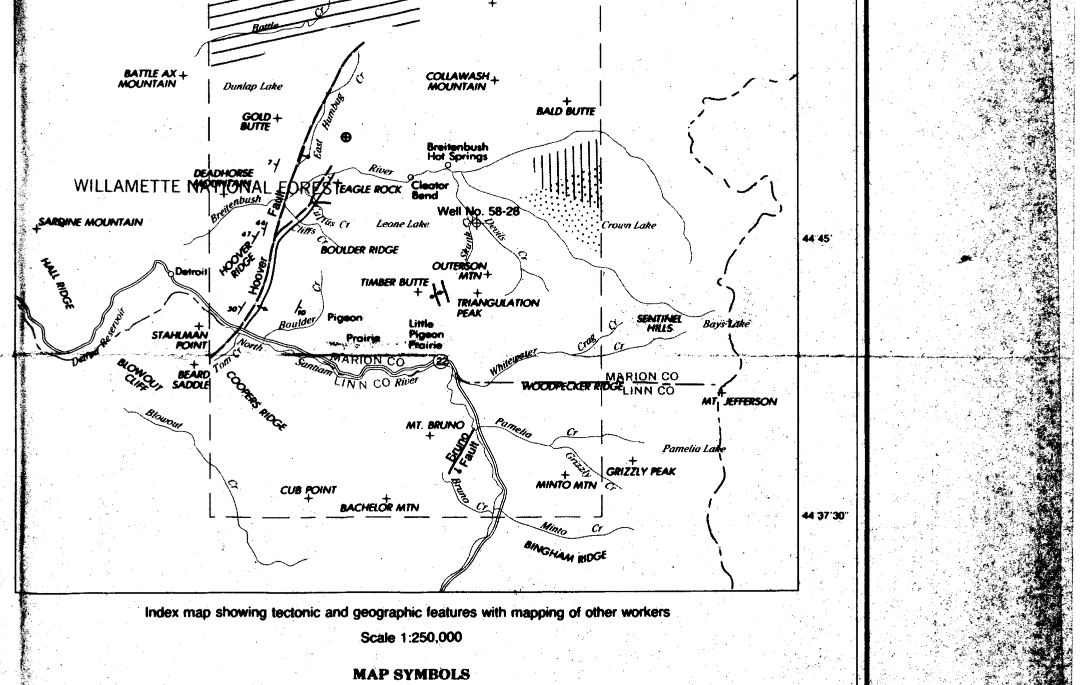
Oligocene and lower Miocene volcanic and volcaniclastic rocks

[illegible]

Table 1. K-Ar and fission-track data

Age (Ma ± 1σ)	Sample no.	Geologic unit	Material dated	K (%)	Ar	Location T.(S.)R.(E.) sec.	Latitude (N)	Longitude (W)	Footnotes
0.27 ± 0.02	MS-238	Tp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.292 ± 0.017	NS-212	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.46 ± 0.21	MS-237	Tp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.59 ± 0.14	NS-209	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.681 ± 0.034	NS-217	QTbb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.7 ± 0.1	NS-446	Tub	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.87 ± 0.18	MS-258	Tmb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3.06 ± 0.05	NS-225	Tub	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3.70 ± 0.05	DMS-47	QTa	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.18 ± 0.07	NS-149	Tc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.2 ± 0.3	PH-1D	Tc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.67 ± 0.07	DMS-50	Tmb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.74 ± 0.19	CT-68	Tc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.77 ± 0.08	NS-151	Tc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.99 ± 0.18	NS-733	Tmb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5.34 ± 0.53	Devil-440	Tmb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5.75 ± 0.10	MS-239	Tib	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.0 ± 0.9	DC-14	Tp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.1 ± 0.31	CT-17	Tc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.30 ± 0.22	DC-114	Tp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.35 ± 0.15	NS-308	Tp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.42 ± 0.33	NS-449	Tmb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9.5 ± 1.3	DC-4	Tp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10.4 ± 1.2	PH-40A	Tmt	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11.2 ± 0.8	DMS-40	Tma	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11.5 ± 0.2	Bx 193, DMS-49	Tmb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11.8 ± 0.4	CT-59	Tma	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.3 ± 0.2	PEH-77-10	Tmt	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.3 ± 0.8	No. 4	Tbp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.6 ± 0.2	FRL-4825	Tmt	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.7 ± 0.8	No. 4	Tbp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14.5 ± 0.2	PEH-77-9	Tla	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14.7 ± 0.2	PEH-77-9	Tla	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14.8 ± 0.9	FRL-4824	Tla	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15.4 ± 1.0	FRL-4824	Tla	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17.7 ± 0.3	MS-256	Tla	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17.6 ± 0.2	MS-256	Tla	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	—	Tbp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19.4 ± 0.4	CT-14	Ts	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20.3 ± 0.2	Bx 102, DMS-43	Tbq	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22.0 ± 0.2	CT-11	Tbu	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22.1 ± 0.5	NS-826	Tls	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23.2 ± 0.8	FRL-4823	Tbl?	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24.3 ± 1.1	PEH-77-8	Tbl?	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24.9 ± 0.3	Bx 99	Ts	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25.5 ± 0.8	CT-8	Tis	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1. From Sutter, 1978.
2. From Laursen and Hammond, 1978.
3. From Hammond and others, 1980.
4. From White, 1980a,b.
5. From Priest and others, 1983.
6. Modified by Fiebelkorn and others, 1983.
7. Location recalculated based on [illegible]
8. Whole-rock samples were dated at [illegible] University of Arizona, Tucson, Arizona [illegible]
9. Sample is from a unit not exposed [illegible] immediately east of Pamelia Lake.
10. Sample is from a unit not exposed [illegible] Bays Lake. Sample is from units [illegible]
11. Sample is from outside the map area [illegible]
12. Date may be affected by low-grade [illegible]



Index map showing tectonic and geographic features with mapping of other workers

Scale 1:250,000

MAP SYMBOLS

- Fault — ball and bar on downthrown side
- Probable plunging anticline
- Strike and dip of beds
- Horizontal beds
- Boundary of geologic map of this study
- Geologic mapping of others:
  - Walker and others, (1985)
  - Hammond and others, (1982)
  - Conrey, R.M., written communication, 1986

EXPLANATION

SURFICIAL UNITS

[illegible]

VOLCANIC UNITS

[illegible]

Tla — **Lower andesite sequence (lower Miocene)** — Two-pyroxene andesite lavas interbedded with unit **Tbu** and the upper part of unit **Ts**. The rocks are mostly highly porphyritic with 1- to 5-mm-long plagioclase, clinopyroxene, and orthopyroxene set in a fine-grained groundmass of devitrified to hydrated glass that is completely altered to zeolite and clay in some areas (e.g., west Coopers Ridge). Where glass is altered to clay, orthopyroxene is mostly altered to greenish smectite clay. In the most intensely altered rocks, the plagioclase is also partially to completely altered to clay and zeolite. The unit varies in thickness from 30 to 240 m. The thickest exposures are on the southwest [illegible]

VENT COMPLEXES

[illegible]

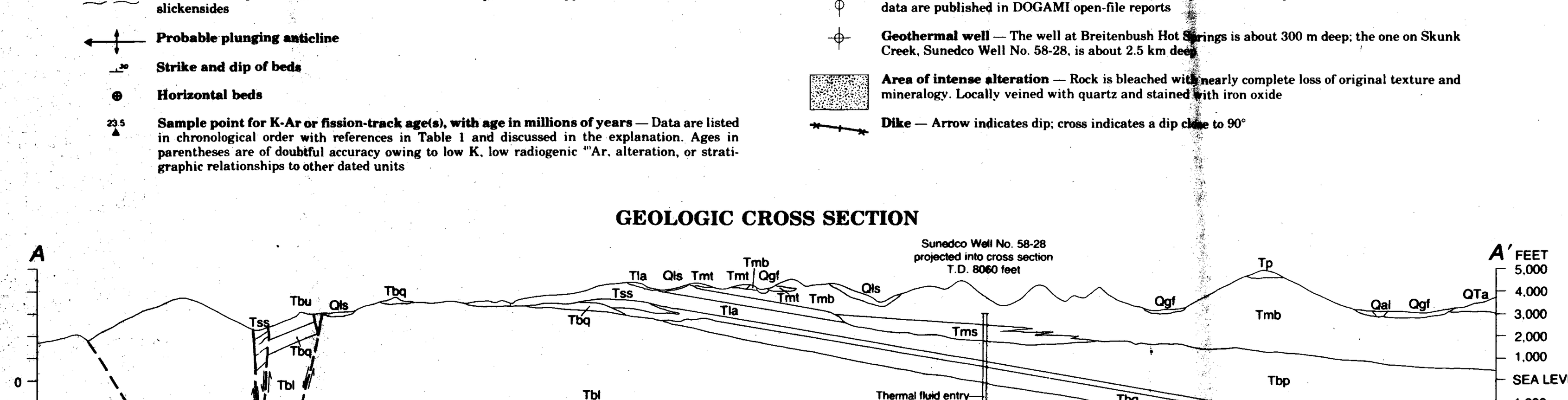
INTRUSIVES

[illegible]

MAP SYMBOLS

[illegible]

GEOLOGIC CROSS SECTION



SEE ACCOMPANYING TEXT FOR THE LIST OF REFERENCES AND A DISCUSSION OF THE REGIONAL GEOLOGIC SETTING